Diamond: from Wedding Ring to Eye Retina

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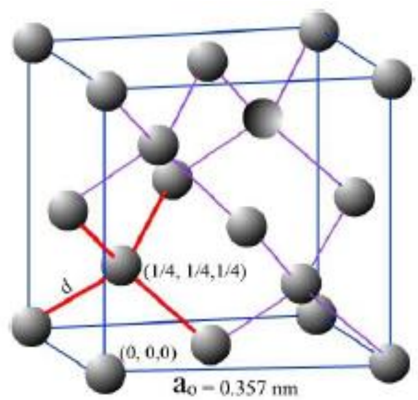
Diamond is a most precious material and is endowed with outstanding properties. It holds tremendous potential for the new generation technology. Once known as a girl's best friend, diamond is now the most researched material in scientific community. In Greek, diamond means unbreakable. It is an allotrope of sp^3 bonded carbon atoms and is transparent for a wide range of electromagnetic radiation. Due to the small size of the carbon atom and its ability to bond together, diamond is one of the strongest materials with many superlative properties. If such properties can be exploited successfully, it offers myriads of uses to humanity in many realms of life.

Natural diamonds are rare and their flaws prevent them from being utilized in many areas of research and technology. Twentieth century scientists have found an efficient and cost effective method to produce flawless diamond in the laboratory. At present, diamond is being synthesized by two major processes, namely the High Pressure and High Temperature (HPHT) process and the Chemical Vapor Deposition (CVD) process. The HPHT process replicates natural diamond formation in the Earth's crust and is mainly limited to single crystal diamonds. The CVD process, on the other hand, can produce diamonds of various shapes, sizes, and thicknesses with high purity. Nanocrystalline diamond, ultracrystalline diamond, diamond like carbon, and single crystal diamond are some of the famous names of CVD grown diamonds. The major advantage of the CVD synthesis is that the properties of diamond can easily be tuned during the deposition process and one can have control over quality and defects. Various forms and levels of doping in CVD diamond opens up the possibility of its exploitation in future electronics, electrochemical devices, and biomedical applications. Boron and phosphorus are highly explored dopants for making P-type and N-type diamond semiconductors. Highly boron doped diamond has recently been reported to have superconducting behavior at about 4K.



Carbon atoms in diamonds are arranged in a strong tetrahedral structure. The unit cell of a diamond is shown in the figure at left. Here a_o is the cubic lattice constant and d is the $C-C$ bond length of $0.154nm$. The four thick lines represent a tetrahedral geometry. The small size of a carbon atom and the tight covalent bond of carbon atoms in diamond structures are responsible for almost all of its unique mechanical, chemical and electronic properties.

Diamond can be deposited on diamond or non-diamond substrates by using the vapor phase of carbon at a pressure less than one atmosphere with a substrate temperature of 600^oC to 1200^oC. At such conditions of pressure and temperature graphite is the most stable form of carbon.However, the environment inside the CVD chamber is so adjusted that it favors the diamond growth and suppress the graphitic formation. CVD system requires activation energy and a mixture of some form of carbon precursor with hydrogen or inert gas to grow diamond. Methane is the most widely used reactant gas in the CVD diamond process. Since CVD is a kinetic controlled process rather than thermodynamic, hydrogen plays an essential role in diamond deposition. Hydrogen etches graphite much faster than it etches diamond; hence it prevents graphitization by terminating carbon dangling bonds in CVD diamond growth. Any material that can withstand the deposition temperature and can support nucleation and growth of diamond can be used as a substrate for polycrystalline CVD diamond. The single crystal diamond growth in CVD adopts a homoepitaxy process where a film of one material grows on the top of a substrate of the same material. Since the substrate acts as a seed crystal, the deposited film takes the same orientation and lattice structure as that of the substrate. This process grows a higher purity diamond than the substrate itself and can deposit films with different doping levels.

The coatings of CVD diamond films on many tribological (friction causing) devices such as cutting tools, heat sinks, and implant materials can help increase their lifespan because of the high thermal conductivity, biocompatibility, chemical inertness, and low coefficient of friction of diamond. While the high refractive index, high dispersive power, and high transparency of diamond are being enjoyed in jewelry and optical windows. The wide band gap, low dielectric constant, high resistivity, and the radiation hardness lead to applications in many semiconductor industries. Low capacitance (or low dielectric constant) of diamond can be utilized in fast switching electronic devices such as thyristors and insulated gate bipolar transistors (IGBTs). The high carrier mobility, high saturation velocity, and doping capability of diamond makes it a unique candidate for high-power/high-frequency electronics.

Due to a thermal bottleneck, existing integrated circuit (IC) chips and many other high packaging electronic devices rely on large area assembly and high cooling maintenance system. If diamond can be used for these applications all these shortcomings will be overcome with high throughput. Quantum computing, hadron collider instrumentation, and increased lifespan of devices, all could be possible due to synthetic diamond. Synthetic diamond has been in constant exploration in wastewater treatment, electroanalysis, organic synthesis, and sensor areas. Its application in producing a very powerful laser with a greater range of color has recently been studied. Researchers have also begun studying diamond as a potential drug-delivery agent to fight liver and breast cancer. It has recently been experimented to implant diamond electrodes in eye retina to help the blind see again. Hence we can say that *"Diamond is as useful in technology as it is beautiful in a wedding ring"*.